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Published in:
De Economist

Publication date:
1992

DE ECONOMIST 140, NR. 2, 1992

RECONSTRUCTING GROWTH THEORY: A SURVEY**

BY

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1 INTRODUCTION

The recent productivity slowdown in a number of rich countries and diverging growth performances of developing countries have led to a renewed interest in the theory of economic growth. Neo-classical growth theory developed in the early sixties focussed on the contribution of labour and capital to the process of economic expansion and change. In its different guises, either as growth accounting (*e.g.* Denison (1985)) or as a theory of long-run tendencies (*e.g.* Solow (1970)), there was still much to explain. Growth accounting generates a substantial residual, which cannot be explained and is attributed to exogenous technological change. In the long-run tendencies theory the long-run rate of growth depends exclusively on exogenous factors like population growth and labour-augmenting technological change.

The basic idea of the new growth theory is to endogenise the long-run rate of economic expansion. This can be done in different ways. A first and most direct approach is to postulate a technology with a core of reproducible capital goods that is produced without the direct or indirect need for non-reproducible inputs or factors that are available in fixed supply (Rebelo (1991)). Whereas this view is reminiscent of Von Neumann (1938), the second approach finds its origin in externalities of the Marshallian type. By learning, agents take advantage of what other agents do or have done. As a result, the technology may exhibit non-decreasing returns in the reproducible factors. A third line of research relates expansion to some 'engine of growth,' which could be the creation of new knowledge or R & D activities. The technology in the engine-of-growth sector has the Von Neumann-Rebelo features as mentioned above and again externalities may play a role. Externalities evoke the question of internalisation in one way or the other. In the present survey we shall skip this question of welfare economics by concentrating on the positive aspects of endogenous growth theory.

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** We are indebted to S. Kuipers, F. van der Ploeg and A. van Schaik for useful comments on an earlier version.

The new developments have spread over a number of fields. Time and space prevent us from going into a number of interesting extensions. In the first place we shall only discuss models for a closed economy. An analysis of the impact on economic growth of international spill-over of knowledge has to wait for another opportunity. Secondly, specific aspects of development economics like endogenous population growth (*e.g.* Becker *et al.* (1990)) or the specific role played by the agricultural sector will not be discussed. Finally, not much attention will be paid to empirical work on endogenous growth largely based on the extremely valuable new data by Summers and Heston (1984, 1988, 1991), which is still in its infancy (*e.g.* Romer (1989a), Barro (1991), Benhabib and Jovanovic (1991)).

The paper is organised as follows. To set the stage and refresh the reader's mind the essentials of neo-classical growth theory are presented in section 2. Theories with technological change related to different forms of learning-by-doing are reviewed in section 3. Theories which assume constant returns to scale in all reproducible factors without explicit reference to learning or other externalities fit into this section. Section 4 deals with models of intentional technological change, where certain economic activities are explicitly aimed at the development of new techniques or skills and in this way form the 'engine of growth' of an economy. Section 5 is dedicated to the new view on economic growth by Maurice Scott (1989). Finding inspiration in the work of Kaldor this author aims at a more fundamental reconstruction of growth theory, which leaves no place for the time-honoured concept of the production function. Hysteresis finds its way because in some of the models levels of variables are path-dependent. History plays a more prominent role in models with multiple long-run growth equilibria, which are on the agenda in section 5. These models allow for different stages of long-run economic growth. As customary the paper closes with some conclusions and evaluations.

Finally, something has to be said about the choices made with regard to the exposition. To make the survey easily accessible the algebra is kept to a minimum. Instead, the theories discussed are explained by simple graphs.[1] One of the features of endogenous growth theory is that savings behaviour has an influence on long-run growth. This result is valid under a broad spectrum of hypotheses with regard to saving. In the present paper we therefore take the liberty to model savings in a way that is most appropriate for the presentation of the different theories. In some cases this means that we postulate a constant macroeconomic saving ratio, while in other cases we resort to consumers who maximize an intertemporal utility function with a constant elasticity of intertemporal substitution and a constant discount rate.

1 Some technical information necessary to derive the relations depicted in the graphs is provided in footnotes. For more formal surveys of some recent developments in the theory of growth, see Romer (1989 a) and Sala-i-Martin (1990).

2 NEO-CLASSICAL GROWTH THEORY AND ITS SHORTCOMINGS

The standard tool of neo-classical growth theory, initiated by Solow (1956, 1957) and Swan (1956), is a production function with diminishing returns to factors when they are changed separately and constant returns to scale when all factors change at the same rate. The properties of such a function are very well known and can be easily applied to a growing economy. For this purpose it is useful to distinguish between reproducible inputs (say capital) and non-reproducible inputs (say labour).

Economic growth results from changes in the quantity and quality of inputs in the production process. Households are guided by intertemporal preferences in deciding how much to consume and how much to save. Firms maximize profits by employing labour and capital and by expanding activities through investment. Under perfect competition all markets clear and savings are equal to investment. In turn, investment adds to the stock of reproducible inputs and allows for growth in production. However, the marginal product of capital declines as the proportion of capital over non-reproducible factors rises. In this way, accumulation contributes less and less to growth and the long-run rate of growth in production will tend to zero unless the quantity and quality of non-reproducible inputs rises. Therefore, a growing effective labour force compensates for diminishing returns with respect to capital and keeps the economy growing. In the long run the rate of growth is entirely determined by exogenous factors like population growth and labour-augmenting technological change. Capital and effective labour then increase at the same rate, the natural rate of growth. The rate of interest and the share of income accruing to labour remain constant.

As observed by Jones and Manuelli (1990) there is a caveat to this story.[2] If labour and capital are easily substitutable, implying that the elasticity of substitution is larger than unity, production may be possible without labour. In this case, accumulation of capital may drive out the non-reproducible factor, so that long-run growth is no longer determined by exogenous factors. Such a scenario seems highly implausible. It will therefore be assumed that the elasticity of substitution between labour and capital is smaller than or equal to unity. Moreover, empirical results in estimating neo-classical production functions point in the same direction.

With this in mind neo-classical growth theory can be illustrated by a simple graph. Assuming a Cobb-Douglas production function and a constant rate of labour-augmenting technological progress (g_h), there is a linear relation between per capita growth of output ($g - g_L$) and per capita growth of capital

2 In fact, Solow (1956) already stresses this point. Many of the nuances made in early contributions to growth theory are suppressed in later 'textbook presentations' but are rediscovered in the recent literature on endogenous growth.

$(g_K - g_L)$ as shown in Figure 1.[3] The slope of the dynamic production function is $(1-\lambda)$, where λ equals the share of income accruing to labour. The vertical intercept of the line is given by λg_h. The long-run rate of growth is obtained at the intersection of the production function and a 45°-line from the origin. As can easily be checked, the long-run rate of growth of output is then equal to the natural rate of growth $(g = g_L + g_h)$. Left of the point of intersection output increases faster than capital, so that for a given savings and investment ratio g_K increases. Right of the point of intersection the situation is reversed and g_K declines. It may be concluded that the model is stable as indicated by the arrows in Figure 1.

The neo-classical model can explain the stylized facts on growth as listed by Kaldor (1961). If the labour force increases at a constant rate and labour-augmenting technological change is constant, then (1) output per worker grows steadily, (2) capital per worker rises at the same rate, (3) the average rate of return on capital is steady, (4) the capital output ratio is constant and (5) the shares of income accruing to capital and labour are constant. However, the way in which the model explains these facts is unsatisfactory. All long-run

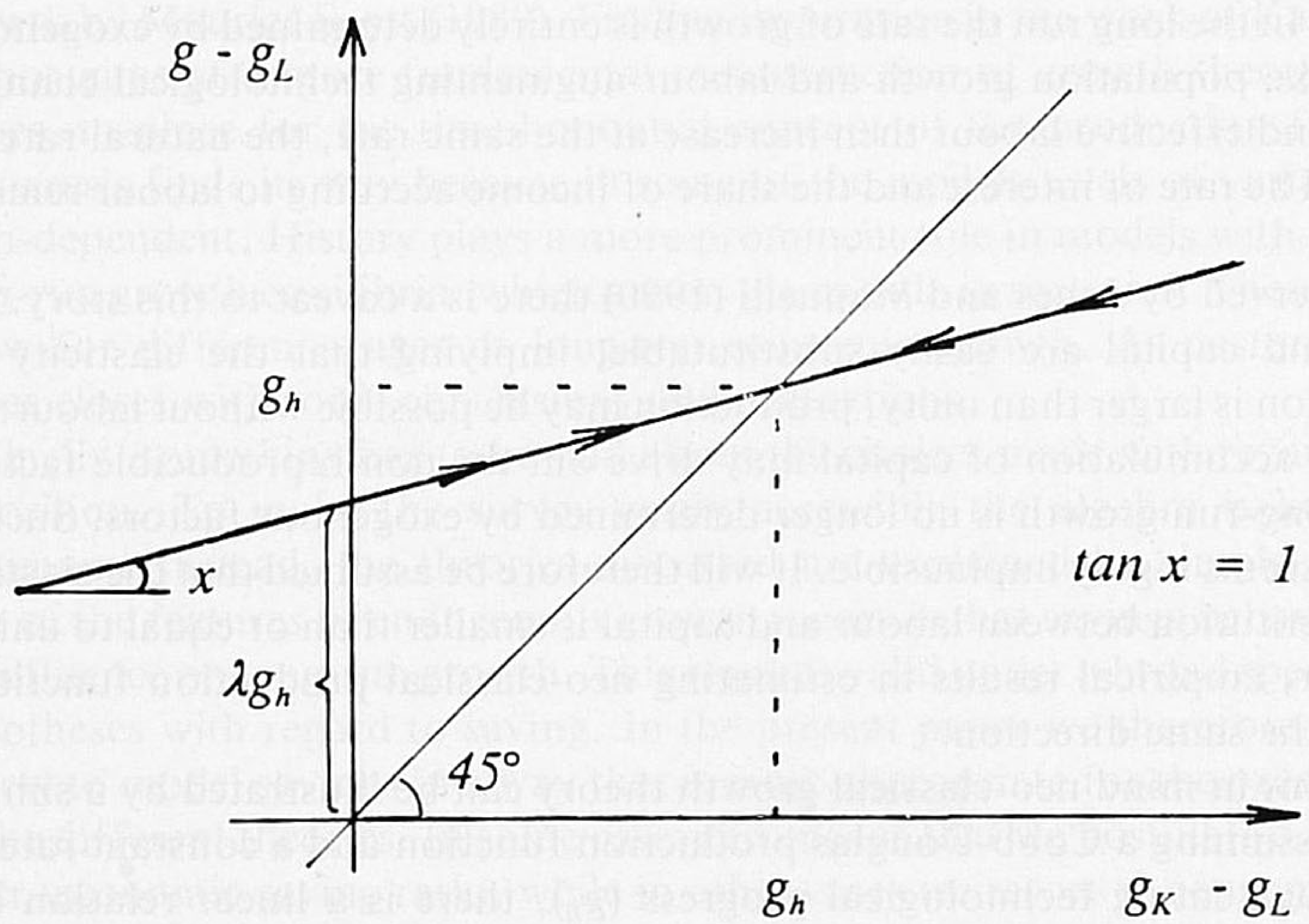

Figure 1 – The neo-classical model (exogenous growth)

3 $Y_t = K_t^{1-\lambda}(h_t L_t)^\lambda$ where Y, K, h and L denote output, capital, the quality of labour and labour. Differentiating with respect to time (t) and defining for any variable x its growth rate as $g_x \equiv (dx/dt)/x$, yields the dynamic production function in the graph. Assuming a constant savings rate σ, g_K is given by $\sigma Y/K = \sigma(hL/K)^\lambda$. Thus $\mathrm{d}g_K/\mathrm{d}t = g_K\lambda(g_h + g_L - g_K)$ which can be used to draw the arrows in the graph.

growth stems from factors outside the model and economic behaviour or policy has no influence on the rate of growth. A change in the savings rate or a change in taxes falling on investment have only temporary effects on economic growth. An intuitively appealing model of growth would allow for permanent effects of savings and taxation by endogenising technological change.

There is even more to be said. In reality one sees great and seemingly persistent differences in growth rates and per capita income levels, whereas the neo-classical model predicts convergence in both variables for countries that are similar in preferences and technology. The observed differentials can be explained by dissimilar rates of technological progress across countries, but again this is not fully satisfactory. Alternatively, one could argue within the neo-classical framework that growth differences are an indication of a transition process towards the steady state. This view is forcefully attacked by King and Rebelo (1990) showing that for reasonable parameter values the neo-classical growth model predicts unrealistically short transition periods. In contrast, Mankiw, Romer and Weil (1990) support the neo-classical paradigm. Taking account of exogenous accumulation of human capital they show that there is a negative correlation between the growth rate of output and the initial level of per capita income. Although this result corresponds to the predictions of neo-classical theory, it can also be explained in a different way. International spill-overs of technological knowledge may lead to a catch-up of countries that lag behind the leader. An adequate index of the technological gap is per capita income in relation to per capita income of the leading country. As there is a fair amount of empirical support for the catch-up hypothesis[4] we prefer this explanation of the negative correlation between growth and the initial level of output.

3 LEARNING-BY-DOING AND OTHER CAUSES OF NON-DECREASING RETURNS

Arrow (1962) argues that labour productivity is not exogenously given, but depends on experience in the production of commodities. A changing environment brought about by continuous investment poses new problems and challenges, which have to be solved. This learning-by-doing is related to cumulative investment in the Arrow model, but the proportionate increase in labour productivity caused by the learning effect might as well be related to the stock of capital. An important point to note is that learning is conceived as a public good. It is an external effect to the individual firm, because the stock of knowledge, which is non-rival and non-excludable, is related to the aggregate stock of capital. Labour productivity depends on experience gained from activities in the entire economy. Therefore, investment and the aggregate capital stock of all firms matter rather than the firm's own investment and capital

4 See *e.g.* Maddison (1987), Abramovitz (1990), Scott (1989), Dumke (1990), Dowrick and Gemmel (1991).

stock. In this way, there may be increasing returns to scale at the level of the economy, but firms can still be confronted with constant returns to scale. The external effects are Marshallian, so that firms can behave competitively without incurring losses.

Until recently, models based on learning-by-doing maintained the assumption of decreasing returns to capital on an economy-wide level (*e.g.* Arrow (1962), Sheshinsky (1967)). The larger the aggregate capital stock per worker, the lower the returns to the firm's stock of physical capital, as in the neo-classical model. In this case diminishing returns are not fully offset by increased knowledge from learning and capital accumulation contributes less and less to growth. Only additions to the labour force (population growth) will make economic expansion sustainable by continually raising the marginal productivity of capital which restores the incentive to invest and to gain experience at the same time.

The Arrow-Sheshinsky model can be illustrated along the same lines as the neo-classical model (*cf.* Stern (1991)). Assuming again a Cobb-Douglas production function with capital, and effective labour as inputs and a constant elasticity (γ) of knowledge with respect to aggregate capital, the relation between per capita growth of output and capital is as shown in Figure 2.[5] The parameter λ is the elasticity of production with respect to labour at the firm level. Furthermore, it is assumed that the elasticity of knowledge with respect to capital is smaller than one ($\gamma < 1$). The long-run rate of growth is obtained at the point of intersection of the technology curve and a 45°-line from the origin. As can be deduced from Figure 2 the long-run rate of growth is equal to $g = g_L/(1-\gamma)$. Population growth is a necessary condition for the growth rate of output to be positive. The long-run equilibrium is stable as can easily be checked.

The implication of the model that the steady-state rate of growth depends upon growth of the labour force is unattractive. Economic growth explained in this way is still exogenous. The long-run growth rate is determined solely by the production technology conditions, as in the neo-classical growth model. To put it in terms of Figure 1 or 2, only one point, the intersection of the technology line and the 45°-line, is consistent with long-run growth. To obtain endogenous growth where besides technology conditions savings behaviour also influences growth, there has to be a range of possible long-run growth rates for given production technology conditions. As a prelude to model specifications which will be given below, it may be illuminating to see how the figure can be adapted to fulfill this requirement. A first way is to change the slope of the technology line in such a way that this line coincides with the 45°-line. The models reviewed in the remaining part of this section fit in with this procedure. Another way is to allow for shifts in the technology line, dependent for instance on the propensity

5 The relations depicted can easily be derived using the same procedure as in footnote 3, now taking into account that $h = K^{\gamma}$, where h is to be interpreted as 'knowledge.'

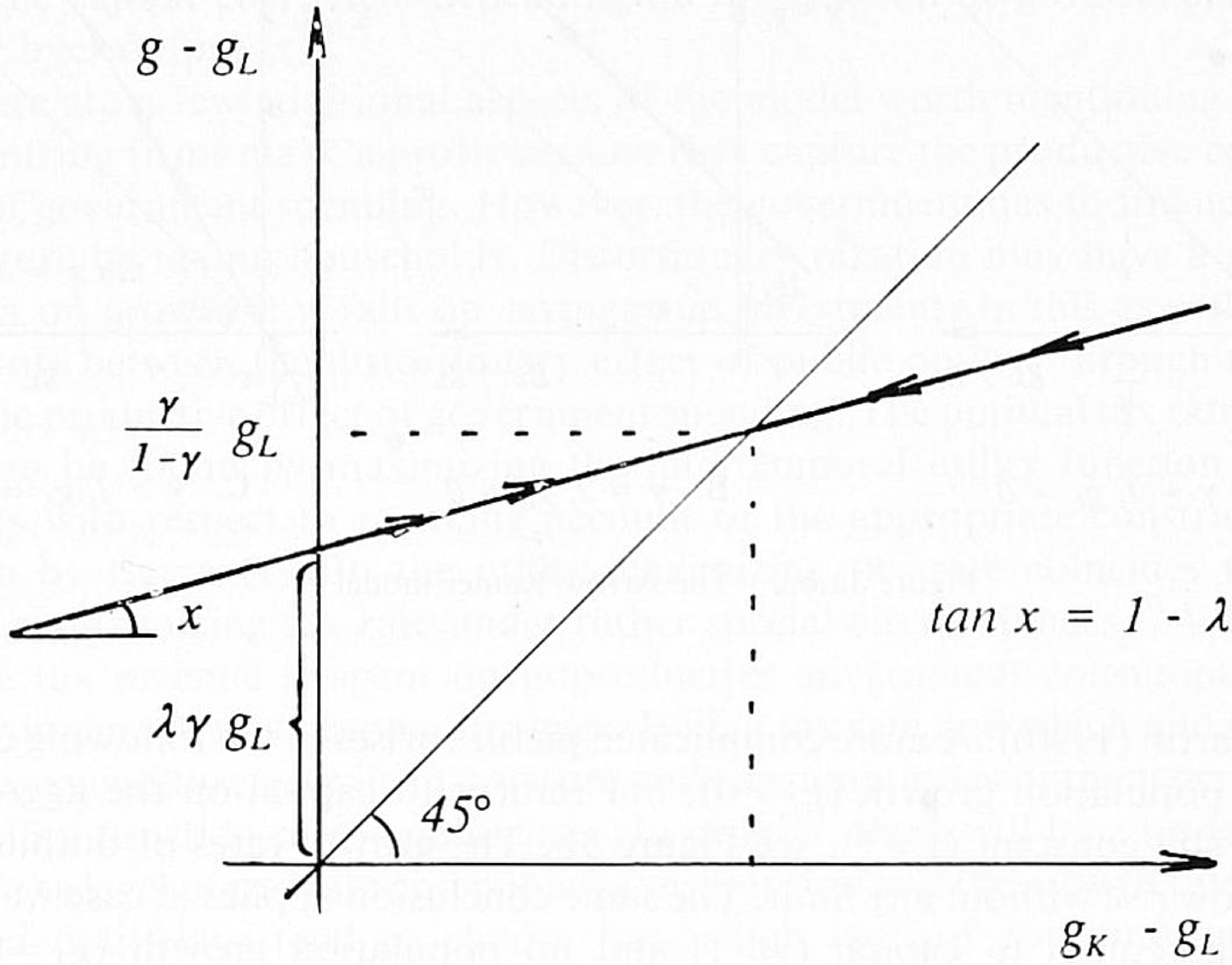

Figure 2 - The Arrow-Sheshinsky model (learning-by-doing)

to save or to invest, which change the point of intersection with the 45°-line and therefore the long-run growth rate. This procedure is illustrative for the Scott model described in section 5.

Romer (1986) took up Arrow's model and showed how the growth rate can be independent of population growth.[6] In Romer's model the growth rate is endogenous, because there are no diminishing returns to the stock of capital on an aggregate level. In terms of the elasticity of knowledge with respect to the capital stock we now have $\gamma \geq 1$. Let the savings ratio be constant, as in the other models discussed. For the growth rate to be steady it must then be assumed that there are constant returns to capital ($\gamma = 1$) and no population growth ($g_L = 0$). Otherwise the capital coefficient will steadily decline and the growth rate of output will increase for ever in our representation of Romer's model. Three different possibilities are presented in Figure 3. The assumptions that lead to Figure 3a are $\gamma = 1$ and $g_L = 0$. In this case the capital coefficient (κ) is constant and consumption, capital and output grow at the same constant rate.[7] Moreover, there are no transitional dynamics in this model (see *e.g.*

6 Much earlier, Conlisk (1967) formulated a model in which learning-by-doing, though not explicitly labeled so, gives rise to endogenous growth. He assumed that the growth rate of knowledge rises with the level of production per efficiency labour unit.

7 Replacing $h = K^{\gamma}$ in the Cobb-Douglas production function (see footnote 3) gives $Y = K^{1-\lambda(1-\gamma)}L^{\lambda}$ and therefore $\kappa \equiv K/Y = K^{\lambda(1-\gamma)}L^{-\lambda}$.

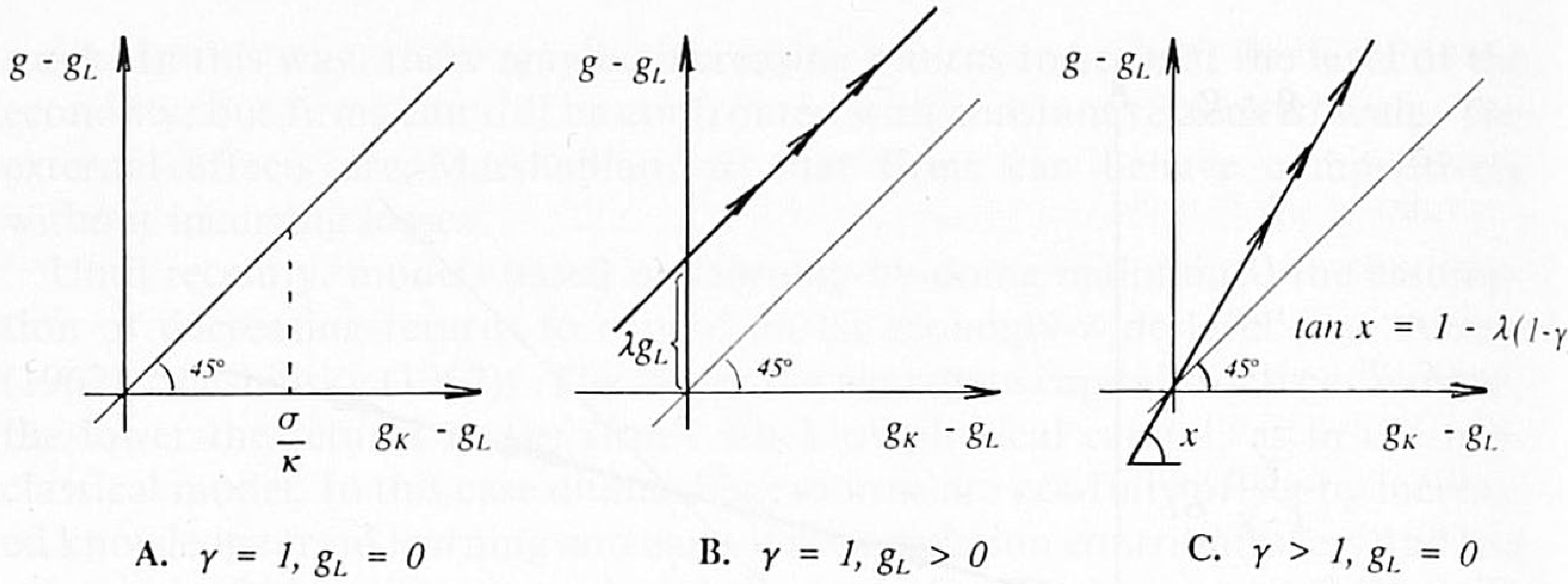

Figure 3a,b,c – The Arrow-Romer model

Sala-i-Martin (1990)). A more complicated picture arises in the following cases. There is population growth ($g_L > 0$), but returns to capital on the aggregate level are still constant ($\gamma = 1$), see Figure 3b. The growth rates of output and capital now rise without any limit. The same conclusion applies in case we have increasing returns to capital ($\gamma > 1$) and no population growth ($g_L = 0$) as shown in Figure 3c.[8]

There is no *a priori* reason to believe that externalities from learning-by-doing are large enough to compensate for internal diminishing returns to capital. Romer (1986) gives some evidence which could point at increasing returns. Growth in the eighteenth century was much slower than current growth rates. Moreover, there are indications that rich countries grow faster than poor countries (with a low stock of capital and knowledge). Although such global facts are hardly conclusive the idea that diminishing returns in a dynamic world of learning and innovation are not dominant is appealing. In section 5 this idea will be taken up again from a different angle.

Besides learning there may be other causes for non-decreasing returns to capital. Barro (1990) introduces productive government spending as an input factor in the production function of the private sector. The production function relating output to capital and public expenditure is linearly homogeneous. In addition, it is assumed that the government spends a fixed proportion of output (τ) on productive outlays. The combination of both assumptions implies constant returns to capital. Capital accumulation induces diminishing returns, but with a fixed τ public expenditure rises in proportion to output. The increase in productive government spending raises the productivity of capital to such an extent that it fully compensates for diminishing returns to accumulation considered in isolation. Therefore, the Barro model fits into Figure 3a,

8 A fourth possibility is $\gamma > 1$ and $g_L > 0$ with an intercept of $\lambda\gamma g_L$, no attainable intersection of the production function with the 45°-line and again increasing growth rates.

with the capital coefficient depending on the fraction of government expenditure over output (τ).[9]

There are a few additional aspects of the model worth mentioning. Profit-maximizing firms make a profit because they capture the productive contribution of government spending. However, the government has to finance its expenditure by taxing households. Distortionary taxation may have a negative impact on growth if it falls on savings and investment. In this case there is a trade-off between the distortionary effect of public outlays through taxation and the productive effect of government spending. The optimal tax rate on output can be found by maximizing the intertemporal utility function of consumers with respect to τ, taking account of the appropriate constraints. As shown by Barro (1990), the utility-maximizing tax rate coincides with the growth-maximizing tax rate under rather special circumstances.[10] When part of the tax revenue is spent on unproductive government consumption, the distortionary effects become stronger. Which tax rate and which allocation of public expenditure over infrastructure and consumption is optimal depends on the utility function of the politicians. In general, there will be a trade-off between the level of (private and public) consumption and the growth rate. Short-sighted politicians tend to choose for a high level of consumption and a relatively high tax rate. Infrastructural provisions and growth will be lower than in a situation where politicians and private agents have the same time preference (Van der Ploeg and Van de Klundert (1991)). The impact of government debt on growth is studied by Alogokoufis and Van der Ploeg (1991). Assuming finite lives, following Blanchard (1985), changes in the stock of private wealth affect consumption and the savings rate, because economic agents want to capture the fruits of their wealth before they die. Hence, with Barro's specification of the production function, debt financing of infrastructural provisions raises the productivity of private capital but lowers the savings rate. Taking both effects into account, there is again an optimal share of social infrastructure.

Returning to the formal structure of these models, the basic property causing endogenous growth is clearly revealed by Rebelo (1991). Production takes place with constant returns to a broad concept of capital which includes capital in the traditional, narrow sense (private capital) and all kinds of other reproducible factor inputs (for instance government spending on infrastructure as in Barro's model).[11] A more realistic description of the production structure

9 Combining the Cobb-Douglas production function $Y = K^{1-\lambda}S^{\lambda}$, where S denotes productive government spending, and the government budget rule $S = \tau Y$ gives $Y = K.\tau^{\lambda/(1-\lambda)}$ and therefore $\kappa \equiv K/Y = \tau^{-\lambda/(1-\lambda)}$.

10 Van der Ploeg and Van de Klundert (1991) show that this result relies on the Cobb-Douglas specification of the production function. Assuming an elasticity of substitution between capital and government spending less than unity, both tax rates do not coincide.

11 Thus, the simplest (one-sector) structure is $Y = A\bar{K}$, where $\bar{K}$ denotes a broad concept of capital (in Barro's model: $\bar{K} = K^{1-\lambda}S^{\lambda}$). This structure can again be represented as in Figure 3a

also distinguishes sectors where non-reproducible factors are essential. Provided that there is a 'core' of capital goods that can be produced without the use of non-reproducible factors, the growth of sectors where capital as well as fixed factors are needed can be fueled without bounds and growth is endogenous. In this case, there is no need for increasing returns and Marshallian externalities as in Romer's (1986) model. This opens up one possibility of modelling technological progress that is fully internalized by firms and consumers, which takes us to the subject of intentional technological change.

4 MODELS OF INTENTIONAL TECHNOLOGICAL CHANGE

It seems unrealistic to assume that all technological changes are side-effects of activities that are not specifically aimed at changing the production environment. When non-reproducible inputs are essential in the production process and the returns from additions to the per capita stocks of these inputs fall, productivity-increasing technological progress is needed to attain long-run growth in per capita terms. To generate these productivity gains, it is, at least to a certain extent, necessary to extract resources from production activities and to use these resources for specific research and education (R&E) activities. In this view, technical progress is not merely a by-product of economic activities, but results from the *intention* to improve upon the existing situation. The allocation of resources and economic activity between the production sector and the R&E sector will be determined by relative returns. The returns on R&E depend, among other things, on the rate of time preference because there is a trade-off between current production and investment in R&E which generates higher future output. Hence, economic growth is endogenous whereby the R&E sector acts as an *engine of growth*, provided that the technology of this sector has the 'core' property in the sense of Rebelo (1991). This idea is not new, but older papers employing it seem to be forgotten, with the exception of Uzawa's article (1965). In the introduction we already referred to Von Neumann (1938). Another rather striking example is Conlisk (1969) who put forward a growth model that is, in essence, identical to Rebelo's model (1991, section III).

In this section we consider two models that apply the engine-of-growth approach. In Lucas (1988) the output of the R&E sector is human capital conceived as knowledge acquired by individuals through intentional learning processes. In Romer (1987) the R&E sector generates technical knowledge,

where now $\kappa = 1/A$. Note the similarity with the Harrod-Domar model (Harrod (1939), Domar (1946)), where a Leontief fixed coefficients production function with capital and labour inputs is assumed. As long as not all labour can be absorbed in production, the marginal productivity of capital is constant and in this case it resembles the Rebelo model. However, once the stock of capital has grown large enough to employ all labour, production capacity is constrained by the labour force. In the $Y = A\bar{K}$-model this kind of bottleneck caused by non-reproducible factors does not arise *ex hypothesi* and exogenous growth is circumvented.

which takes the form of designs for new capital goods which are used in the production of all commodities. Before turning to the details of both models it is useful to discuss some preliminary questions. Firstly, in the preceding sections it was possible to analyse the basic issues by assuming a fixed savings ratio. In the models under review in this section such a simplification is no longer adequate, because the allocation of factors of production between sectors and the intertemporal choice of consumption profiles interact. Following a standard procedure it will now be assumed that consumers maximize an intertemporal utility function with a constant rate of time preference (θ) and a constant coefficient of relative risk aversion (ϱ) (Ramsey (1928)). Combining the first-order conditions for a maximum with the assumption of balanced growth one gets the Ramsey formula: $(g - g_L) = (r - \theta)/\varrho$, where r denotes the real rate of interest and g denotes the common growth rate of aggregate output and consumption. Secondly, in the neo-classical model knowledge is a public good, it is non-rival and non-excludable. Once an idea or, more specifically, a design for a new product or a new production technique exists, it can be applied as often as one likes without further costs attached. This raises a problem if knowledge has to be created by spending on factor inputs. If ideas and designs can be freely copied, the inventor would not be rewarded. Therefore, the fruits of investing in new knowledge should be excludable at least to some extent, so that these investments are profitable (Romer 1990d). In the models this aspect is taken care of in different ways.

Lucas (1988) considers an economy where workers have to decide how much of their time they want to spend on producing goods and how much time they set aside for learning or schooling activities. R&E activities result in higher skills and abilities of workers. Through learning workers invest in human capital, which raises their real wages. Note that knowledge acquired in this manner is rival and excludable because it is tied to individual workers. Firms in the Lucas model face a neo-classical production function which exhibits constant returns in capital and effective labour taken together. The workforce (effective labour) can be enlarged by increasing the number of workers or by raising the skills of existing workers.

To allow for a steady state with growing per capita production and consumption, human capital has to grow steadily. Following Uzawa (1965), Lucas assumes that a constant rate of growth of human capital is attainable by devoting a constant fraction of time to R&E or to learning as it is in this model.[12] This is a disputable assumption if one realizes that knowledge is tied to mortal workers, but it can be given some justification. Learning can be thought of as a social activity in the sense that already existing knowledge can be passed on to new generations. Hence, each generation of workers can assimilate new ideas inspired by the old ideas taught. There is no reason to sup-

12 Rebelo (1991) shows that it can also be assumed that various kinds of reproducible capital are needed for human capital formation.

pose that the generation of Einstein could add less than the generation of Leonardo da Vinci. In other words, there are no diminishing returns and human capital accumulation serves as an engine of growth.

Economic growth depends on decisions taken by optimizing households and firms. The general equilibrium results are somewhat intricate, but the steady-state solution for balanced growth can be represented by the four relations depicted in Figure 4. In this situation, the growth rate of output, capital and consumption are equal and labour productivity increases at the same rate as human capital ($g - g_L = g_c - g_L = g_h$). The fraction of time spent on the production of goods (u) is constant and determined along with the other endogenous variables of the general equilibrium model. For u to be constant, there has to be no incentive to reallocate time between production and education implying that the return to the production of capital goods and the return to education are the same. It can be shown that the real rate of interest then equals $r = \varepsilon + g_L$, where ε is the parameter that relates the growth rate of human capital to the fraction of time spent on education or learning (1-u).[13] In equilibrium, the rate of return on investment equals the rate of return desired by households ($r = \varrho(g - g_L) + \theta$), so that there is no incentive to reallocate production between investment and consumption. This condition is shown in the second quadrant of Figure 4. The simultaneously determined allocation of time (in the fourth quadrant) is found by using the engine-of-growth function, drawn in the first quadrant, as illustrated by the dotted lines connecting the different quadrants in Figure 4. If consumers are in for a lower rate of return the long-run growth rate of the economy will be higher. The same conclusion applies if diminishing returns to capital are more strongly counterbalanced, that is if ε or g_L are higher.

It should be observed that history matters in the present model. In the steady state the capital-effective labour ratio has to be constant. Because both the stock of physical and human capital are endogenous, a country starting from a low level of both factors will ultimately attain the same growth rate as a country starting from a high level of physical and human capital, but the levels will never catch up. There is a convergence in rates of return and growth, but levels will diverge. A relatively poor country therefore remains relatively poor.

A criticism raised against the Lucas model is that intentionally accumulated non-rival knowledge is neglected: education primarily yields skills which are tied to human bodies and therefore rival. Non-rival knowledge that is passed on to future generations is viewed only as a by-product of education (Romer

13 Each consumer maximizes utility by choosing u and the level of consumption C subject to the production function $Y = \mathrm{d}K/\mathrm{d}t + C = K^{1-\lambda}(uhL)^{\lambda}$ and to the engine-of-growth function $\mathrm{d}h/\mathrm{d}t = \varepsilon(1-u)h$. Setting up the Hamiltonian $\mathscr{H}$ and using the optimality conditions for $\partial\mathscr{H}/\partial u$, $\partial\mathscr{H}/\partial K$ and $\partial\mathscr{H}/\partial h$ together with the condition of balanced growth $g = g_K = g_c = (1-\lambda)g_K + \lambda(g_L + g_h)$ yields $r = \varepsilon + g_L$ while the conditions for $\partial\mathscr{H}/\partial C$ and $\partial\mathscr{H}/\partial K$ yield, as usually, the Ramsey formula.

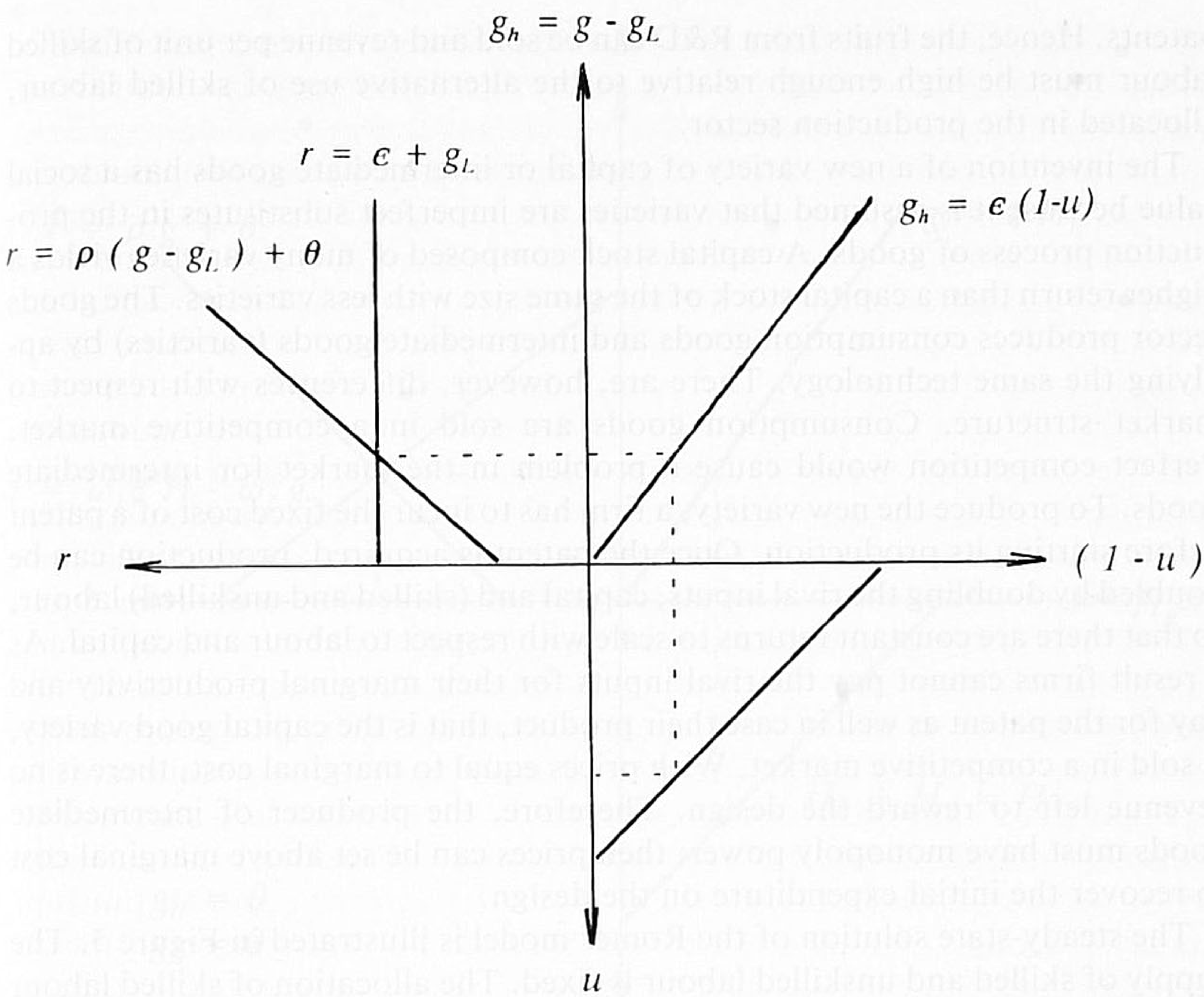

Figure 4 – The Lucas model (human capital accumulation)

1989b). In reality, non-rival knowledge is intentionally accumulated. Scientific research and commercial development primarily yield ideas and designs that can be employed by workers but are not necessarily tied to them.

One way to deal with growth-inducing R&D activities can be found in Romer (1987), who extends Ethier's (1982) static model on specialization to a growing economy. This R&D growth model is used in several other papers, especially in relation to trade.[14] In Romer's version (1987, 1990a,b,c) the engine of growth is the research sector which produces blueprints for new varieties of capital goods which are in turn produced and used in the goods-producing sector. As before there are no diminishing returns with respect to the reproducible factors of production applied in the research sector. For simplicity, skilled labour (called human capital to distinguish it from unskilled labour) is taken as the only input and its productivity is linear in the stock of existing blueprints to emphasize that researchers can benefit from knowledge generated by previous inventions. In this sense, knowledge is non-excludable for researchers. By contrast, the use of blueprints to produce capital goods is excludable by means of

14 Grossman and Helpman (1990, 1991); River-Batiz and Romer (1991a,b); Romer (1990c).

patents. Hence, the fruits from R&D can be sold and revenue per unit of skilled labour must be high enough relative to the alternative use of skilled labour, allocated in the production sector.

The invention of a new variety of capital or intermediate goods has a social value because it is assumed that varieties are imperfect substitutes in the production process of goods. A capital stock composed of many varieties yields a higher return than a capital stock of the same size with less varieties. The goods sector produces consumption goods and intermediate goods (varieties) by applying the same technology. There are, however, differences with respect to market structure. Consumption goods are sold in a competitive market. Perfect competition would cause a problem in the market for intermediate goods. To produce the new variety, a firm has to incur the fixed cost of a patent before starting its production. Once the patent is acquired, production can be doubled by doubling the rival inputs, capital and (skilled and unskilled) labour, so that there are constant returns to scale with respect to labour and capital. As a result firms cannot pay the rival inputs for their marginal productivity and pay for the patent as well in case their product, that is the capital good variety, is sold in a competitive market. With prices equal to marginal cost, there is no revenue left to reward the design. Therefore, the producer of intermediate goods must have monopoly power: then prices can be set above marginal cost to recover the initial expenditure on the design.

The steady-state solution of the Romer model is illustrated in Figure 5. The supply of skilled and unskilled labour is fixed. The allocation of skilled labour (H) between the commodity sector (H_Y) and the R&D sector (H_R) is shown in the fourth quadrant. In general equilibrium the allocation of factors of production is determined simultaneously with the rate of interest as depicted in the second quadrant of Figure 5. Here again the desired rate of return ($r = \varrho g + \theta$) must be equal to the rate of return on physical assets. As appears from Figure 5 the warranted rate of return is a positive function of the stock of skilled labour (H) and a negative function of the growth rate (g). A larger volume of skilled labour leads to a higher input in R&D activities which raises both the growth rate and the rate of return.[15] For a given volume of skilled labour the rate of growth can be increased only by relocating labour from the commodity sector to the R&D sector. As a result of such a reallocation the marginal productivity of capital goods falls, which explains the negative relation between r and g on the supply side of the model. Furthermore, as in the Lucas model a fall in the rate of time preference (θ) or a rise in the effectivity of R&D activities (ξ) leads to a higher long-run growth rate.

It should be noted that the Romer model relies on some old economic insights. Firstly it uses the Chamberlinian approach to increasing returns (Chamberlin (1933)). The economy has increasing returns with respect to

15 With positive population growth, this would imply ever-rising per capita growth rates, as in the Arrow-Romer (1986) model, which seems somewhat implausible.

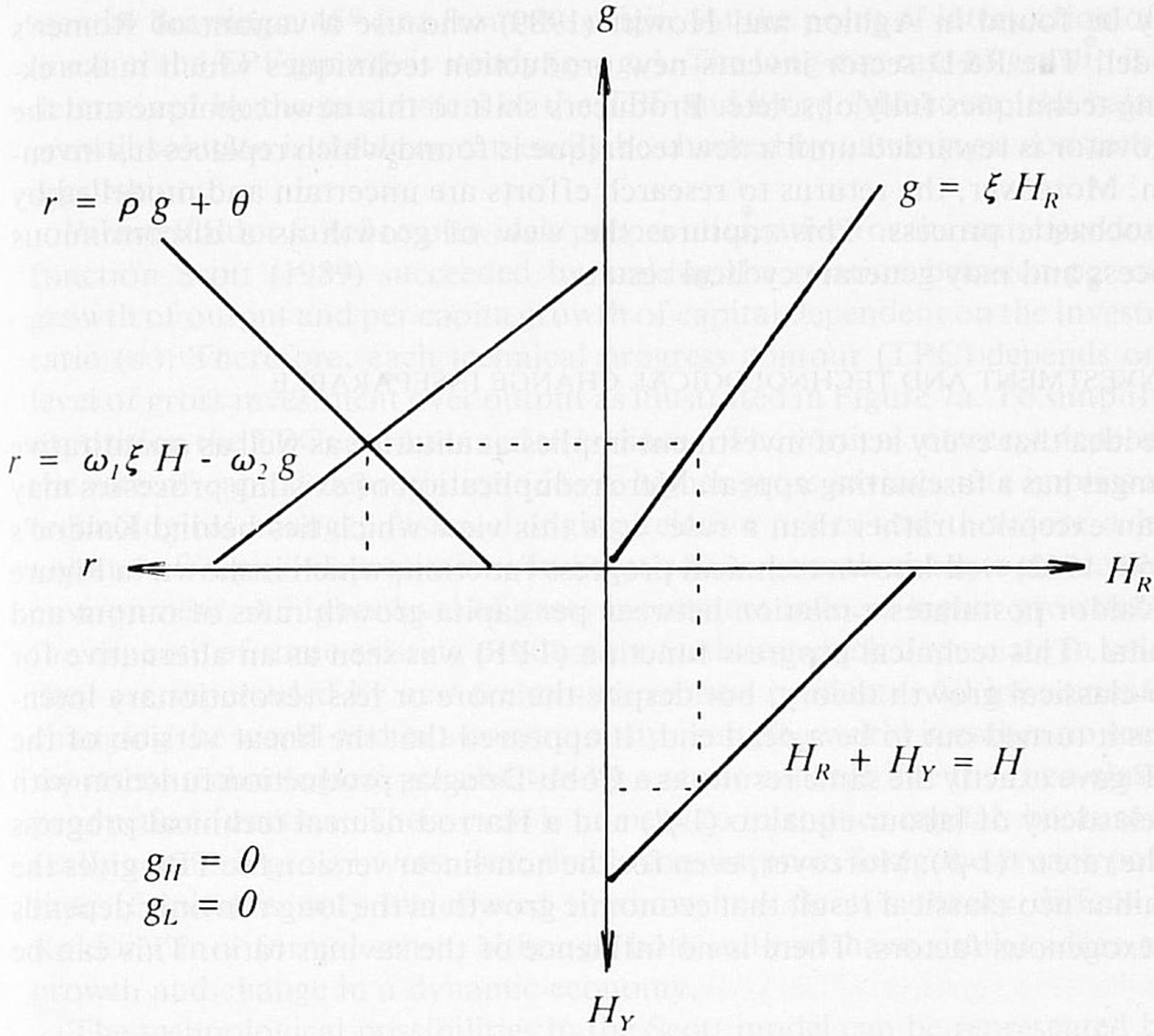

Figure 5 – The R & D growth model (Romer 1987, 1990)

labour, capital and 'knowledge' all taken together. By assuming monopolistic competition, rents can be assigned to the research activities that generate knowledge. Secondly, the model captures some features of Schumpeter's work (1942): growth is driven by the monopoly rents which can be obtained by the introduction of new products, economic change is the result of purposeful activities of profit-seeking entrepreneurs. However, Schumpeter gives a much richer description of economic dynamics, emphasizing discontinuous changes and the importance of disturbances of equilibria. Imitation by entering competitors erodes the innovator's monopoly power. Development of substitutes and new innovations feed the process of creative destruction. It is difficult to capture these dynamics in a tractable formal model.[16] Some recent attempts

16 Romer (1990b) and Grossman and Helpman (1990) assume imperfect substitution between the varieties of capital such that the more varieties are available in the economy, the less the demand for a particular variety is. However, every variety stays in production and thus there is no creative destruction in a strict sense.

may be found in Aghion and Howitt (1989) who use a variant of Romer's model. The R&D sector invents new production techniques which make existing techniques fully obsolete. Producers shift to this new technique and the innovator is rewarded until a new technique is found which replaces his invention. Moreover, the returns to research efforts are uncertain and modelled by a stochastic process. This captures the view of growth as a discontinuous process and may generate cyclical results.

5 INVESTMENT AND TECHNOLOGICAL CHANGE INSEPARABLE

The idea that every act of investment implies qualitative as well as quantitative changes has a fascinating appeal. Mere reduplication of existing processes may be an exception rather than a rule. It is this view which lies behind Kaldor's (1957, 1962) well-known technical progress function, which is shown in Figure 6. Kaldor postulates a relation between per capita growth rates of output and capital. This technical progress function (TPF) was seen as an alternative for neo-classical growth theory, but despite the more or less revolutionary intentions it turned out to be a dead end. It appeared that the linear version of the TPF gave exactly the same results as a Cobb-Douglas production function with an elasticity of labour equal to (1-β) and a Harrod-neutral technical progress at the rate $\alpha/(1-\beta)$. Moreover, even for the non-linear version the TPF gives the familiar neo-classical result that economic growth in the long run only depends on exogenous factors. There is no influence of the savings ratio. This can be

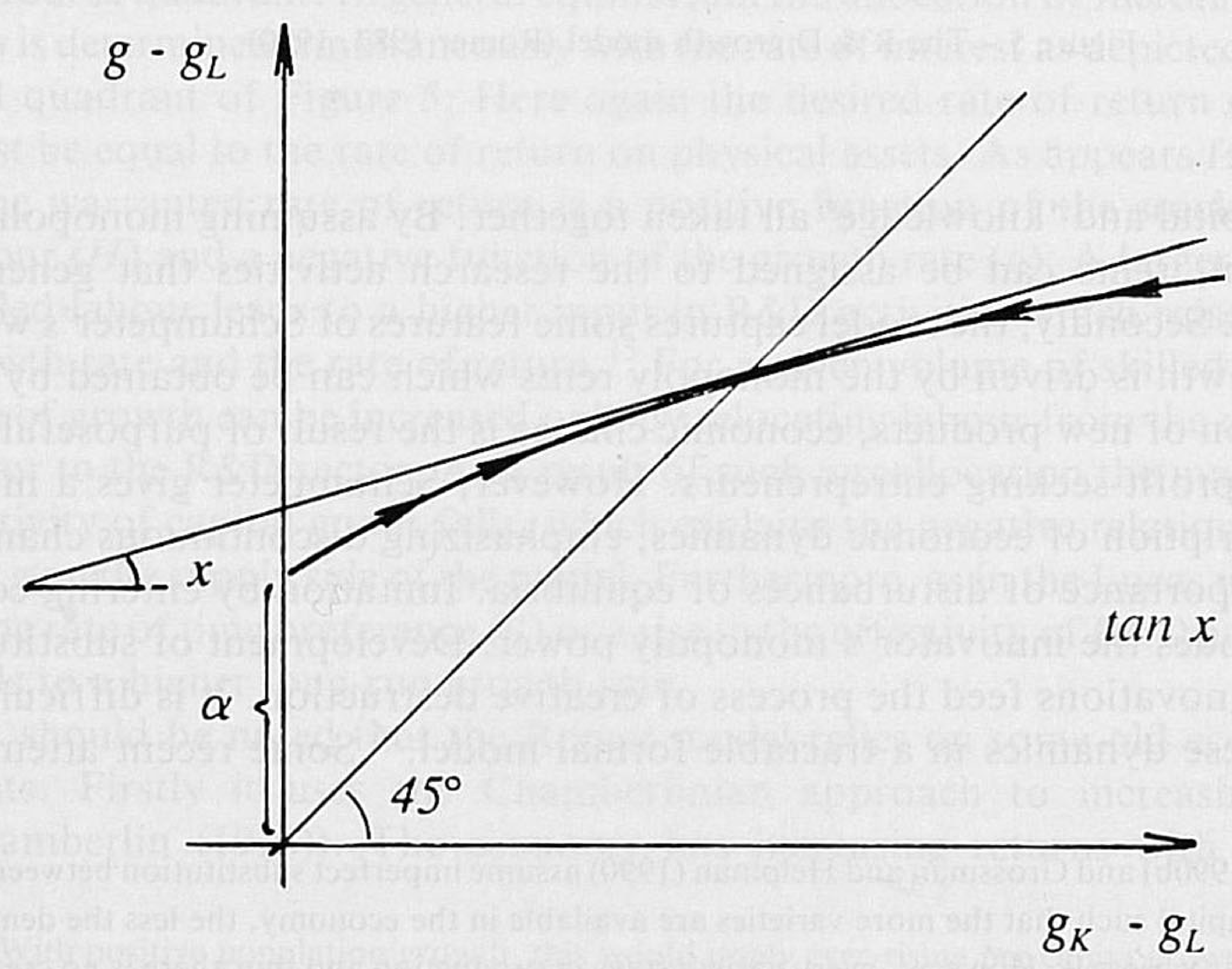

Figure 6 – Kaldor's Technical Progress Function

seen by drawing a 45°-line from the origin. At the point of intersection of this line and the TPF growth is steady ($g=g_K$). The long-run rate of growth is then determined by the parameters of the TPF and by g_L. Moreover, the balanced growth solution is stable as can easily be checked by assuming a constant savings ratio.

Where Kaldor failed to provide a proper alternative for the static production function Scott (1989) succeeded by making the relation between per capita growth of output and per capita growth of capital dependent on the investment ratio (σ). Therefore, each technical progress contour (TPC) depends on the level of gross investment over output as illustrated in Figure 7a. To simplify the exposition the TPCs are assumed to be linear. The vertical intercept depends on the rate of capital depreciation (δ). A higher gross savings rate implies more technological change, faster changing relative prices and therefore a larger volume of capital depreciation. In Scott's view growth changes the economic environment. A higher level of gross investment induces higher growth but at the expense of some existing production facilities which depreciate in value as they are superseded by new techniques or new products. All investments are changing the world and in a continuously changing world it makes no sense to represent technological possibilities by a static concept like the (neo-classical) production function. There even is no need to introduce capital, because what really counts is gross investment, that is consumption foregone at each point in time. Capital is only introduced to show how Scott's theory differs from Kaldor's in a formal sense, although both authors have similar ideas about growth and change in a dynamic economy.

The technological possibilities in the Scott model can be represented by investment programme contours (IPCs). As shown in Figure 7b, these IPCs express how the growth rate of output, measured as the per percent of current output devoted to investment, g/σ, is related to the growth rate of employment, measured in the same way, g_L/σ. Employment growth is corrected for the number of hours worked and the skill level. It is therefore measured in efficiency units. Investment is gross of depreciation but net of wear and tear (*cf.*

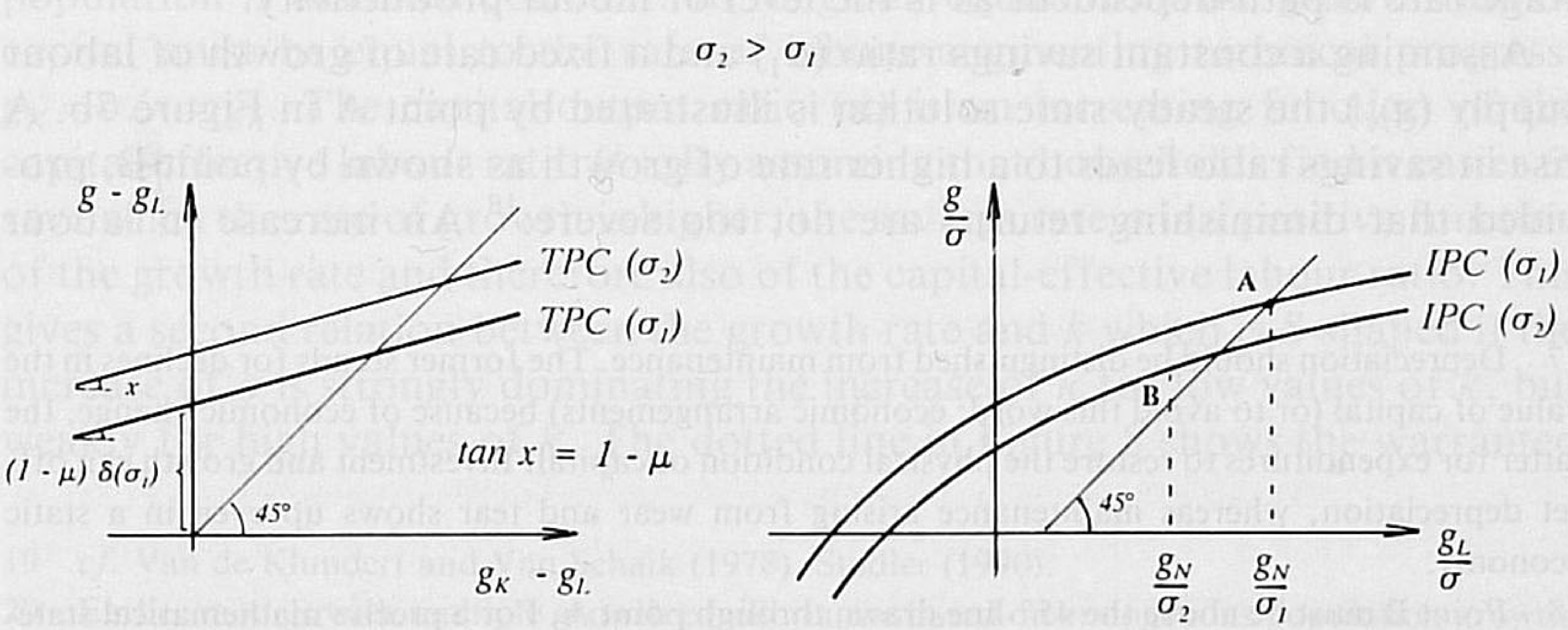

Figure 7a,b – The Scott model

Scott (1991)). When machines or plants depreciate in value as a result of relative price changes they have to be adjusted or replaced to maintain the profitability of the firm.[17] All investment, including replacement of obsolete machines contributes to growth in the form of Schumpeterian creative destruction. Each IPC shows how firms can opt for relatively more labour-saving projects (defensive investment, to the left of the IPC, see Figure 7b) or go for relative more expansionary programmes (offensive investment, to the right of the IPC). Along with this strategic choice firms have to decide on the total amount of investment. A higher investment ratio implies a higher growth rate as the opportunities for learning-by-doing increase. At the same time the qualitative change caused by current investment in new techniques and products creates possibilities for further improvements by future investment so that there is no reason for diminishing returns over time. However, there are diminishing returns with respect to investment in each period as illustrated in Figure 7b. The higher the investment ratio the lower the corresponding IPC will be.

Firms maximize the present value of the cash flow by choosing σ, g and g_L optimally given the time path of real wages and interest rates. If labour is relatively expensive firms will select more labour-saving projects and adapt the volume of investment accordingly. High interest rates make investments relatively unattractive. The model can be completed by introducing utility-maximizing households and assumptions with respect to market clearing. The goods market clears instantaneously. Equilibrium in the labour market is here defined as the equality of the growth rates of employment and labour supply ($g_L = g_N$). However, it is not necessary for the volume of employment to equal the volume of labour supply. Employment and output are path-dependent variables in the model. The steady-state solution appears to be stable for different assumptions with regard to labour market clearing (see Van de Klundert and Meijdam (1991)). The complete model generates solutions for the rate of interest, the savings-investment share and the growth rate of real wages along with a solution for the share of income accruing to labour. The level of the real wage rate is path-dependent as is the level of labour productivity.

Assuming a constant savings ratio (σ_1) and a fixed rate of growth of labour supply (g_N) the steady-state solution is illustrated by point A in Figure 7b. A rise in savings ratio leads to a higher rate of growth as shown by point B, provided that diminishing returns are not too severe.[18] An increase in labour

17 Depreciation should be distinguished from maintenance. The former stands for declines in the value of capital (or to avoid this word: economic arrangements) because of economic change, the latter for expenditures to restore the physical condition of capital. Investment and growth can offset depreciation, whereas maintenance arising from wear and tear shows up even in a static economy.

18 Point B must be above the 45°-line drawn through point A. For a precise mathematical statement of this condition see Van de Klundert and Meijdam (1991).

supply induces a higher growth of output, but labour productivity falls as the slope of the IPC is smaller than one (see Scott (1989)).

From an empirical point of view the Scott model gives satisfactory results, although there seems to be a problem with respect to the explanation of the productivity slow-down after 1973 in a number of countries. This may be due to the impact of substantial negative demand shocks on medium-run growth. Whereas most theories of growth deal with the supply side only, the empirical implementation of the Scott model shows that demand factors cannot be entirely left out. However, a theory integrating both sides of the economy has still to be developed.[19]

6 MULTIPLE GROWTH EQUILIBRIA: HISTORY SETS THE TONE

In the real world economies may be distinguished by stages of growth as suggested by several authors (*cf.* Rostow (1961), Olson (1982), Porter (1990)). At a low level of per capita income countries may be caught in a low growth trap from which it is difficult to escape. More developed countries are supposed to be in a stage of high and sustained growth. But as these economies become more mature things may worsen and there may be a stage with high income but a slowly growing or stagnating economy. The theory of endogenous growth can be extended to allow for different long-run growth equilibria, which can be associated with stages of growth at different points in the spectrum.[20] Here we shall discuss two recent theories, which give rise to multiple equilibria, but which are otherwise different in scope. Stiglitz (1987) highlights the problems of countries trapped in a low-level equilibrium, while King and Robson (1989) develop a model where relatively rich economies stagnate.

In the analysis of Stiglitz, it is assumed that learning depends on the capital-effective labour ratio (k). Labour-augmenting technical progress (g_h) is a positive function of k, because when a more capital-intensive technique is employed, technological spill-overs are stronger and learning of technical skills is easier. The learning function is convex as shown in Figure 8. For simplicity, population is assumed constant. In long-run equilibrium the growth rate of capital must be equal to the rate of labour-augmenting technical progress: $g_K = \sigma/\kappa = g_h$. The capital-output ratio (κ) is an increasing function of the capital-effective labour ratio (k). By assuming that households find it easier to save when the rate of growth is higher, the savings rate σ is a positive function of the growth rate and therefore also of the capital-effective labour ratio. This gives a second relation between the growth rate and k which is S-shaped if the increase of σ is strongly dominating the increase of κ for low values of k, but weakly for high values of k. The dotted line in Figure 8 shows the warranted

19 *cf.* Van de Klundert and Van Schaik (1978), Stadler (1990).

20 Earlier models with multiple growth equilibria are based on endogenous population growth, *e.g.* Nelson (1956), Buttrick (1958) and Niehans (1963).

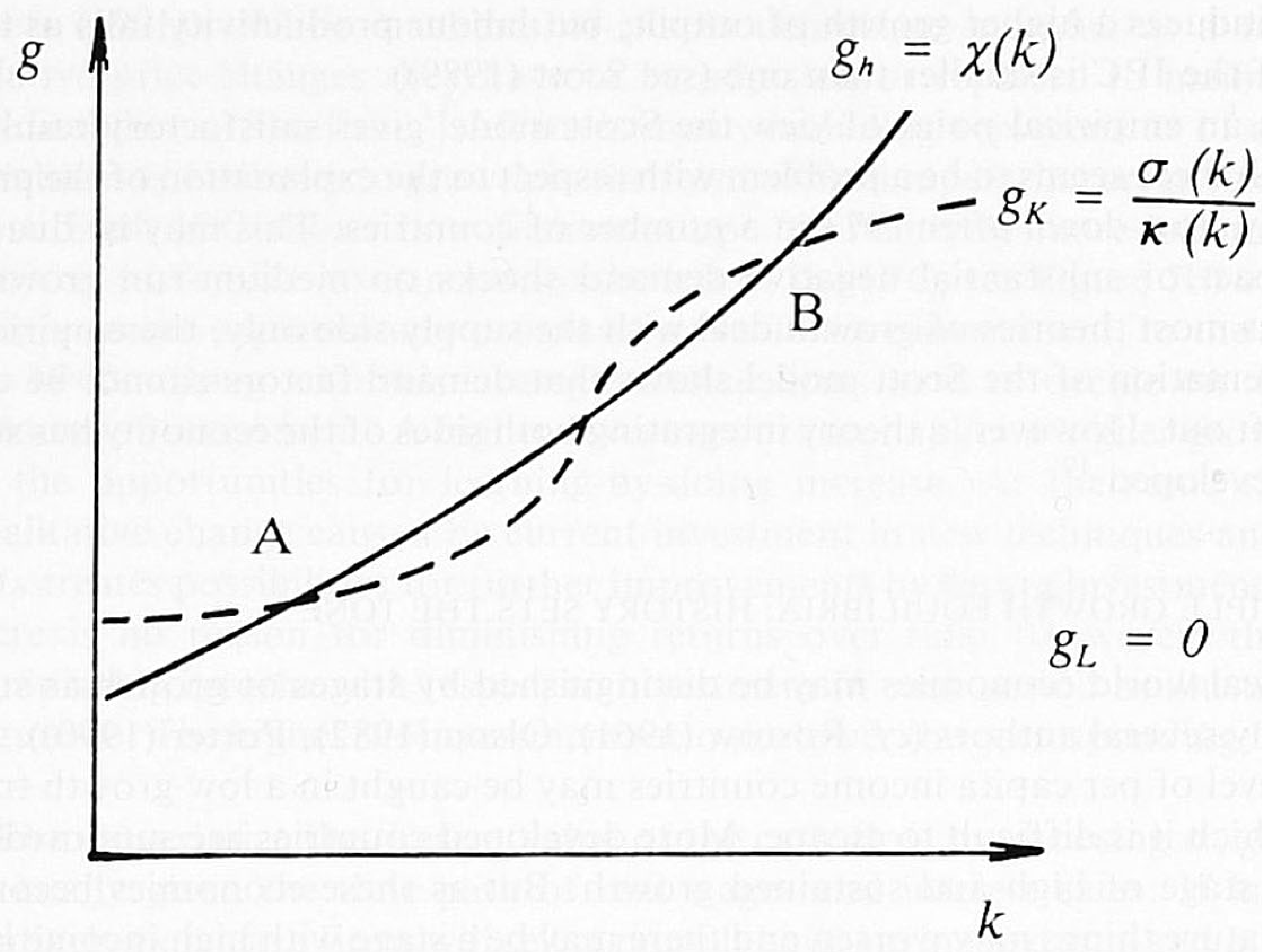

Figure 8 – The Stiglitz model (learning to learn)

rate of growth as a function of the capital-effective labour ratio. There are three long-run equilibria, with stable solutions at points A and B.

In the low-level steady state the savings rate is low because the rate of growth is low, whereas the growth rate is low because technical progress is modest. In turn, technical progress is low because firms apply techniques with a limited learning potential. The country is therefore trapped in a low-level equilibrium from which it is difficult to escape. The situation is even worse if the learning capacity of the economy depends on k as well as on current and past learning experiences. In particular, with a low level of learning capacity the immediate benefits of a switch to a more capital-intensive production process may be limited as it takes additional time to generate sufficient learning experience.

In the model of King and Robson (1989) it is the high income country that realizes slow output growth. Maturity induces rent-seeking, lack of motivation and emphasis on distribution rather than production (*e.g.* Olson (1982), Porter (1990)). King and Robson assume that production per efficiency unit of labour depends on capital per efficiency unit of labour with a constant elasticity $1-\lambda$. There is no population growth. Capital depreciates because of wear and tear at a constant rate δ. Firms invest to the point where the marginal product of capital equals the sum of the real rate of interest and the depreciation rate: $(1-\lambda)/\kappa = r+\delta$. Technical progress, which takes the form of labour-augmenting technological change, is assumed to depend on the rate of investment net of depreciation (σ). This represents the effect of learning-by-watching, the demonstration effect on productivity of what is going on in the economy as a whole. Learning-by-watching is a Marshallian external effect.[21] The technical progress function of Robson and King differs in this respect from the innovation possibility contour of Scott, which relates learning to the own experience and intentions of firms. The King-Robson technical progress function is S-shaped as shown in Figure 9 by the curve $g=\varphi(\sigma)$. At low levels of investment the probability of contact with new ideas is supposed to be low. The growth rate increases with a rise in the investment ratio, but beyond a certain level the demonstration effect has less impact because of saturation effects and limited possibilities to absorb new ideas. As these factors gain importance it is hardly possible to raise the growth rate by investing more.

The warranted long-run rate of growth depends on the savings ratio and the interest rate according to the formula $g=\sigma/\kappa=\sigma(r+\delta)/(1-\lambda)$. Intertemporal choice of consumers leads to the well-known Ramsey formula: $g=(r-\theta)/\varrho$. Combining both equations leads to an expression for the growth rate as a function of the investment rate: $g=(\theta+\delta)\sigma/(1-\lambda-\varrho\sigma)$, which is illustrated in

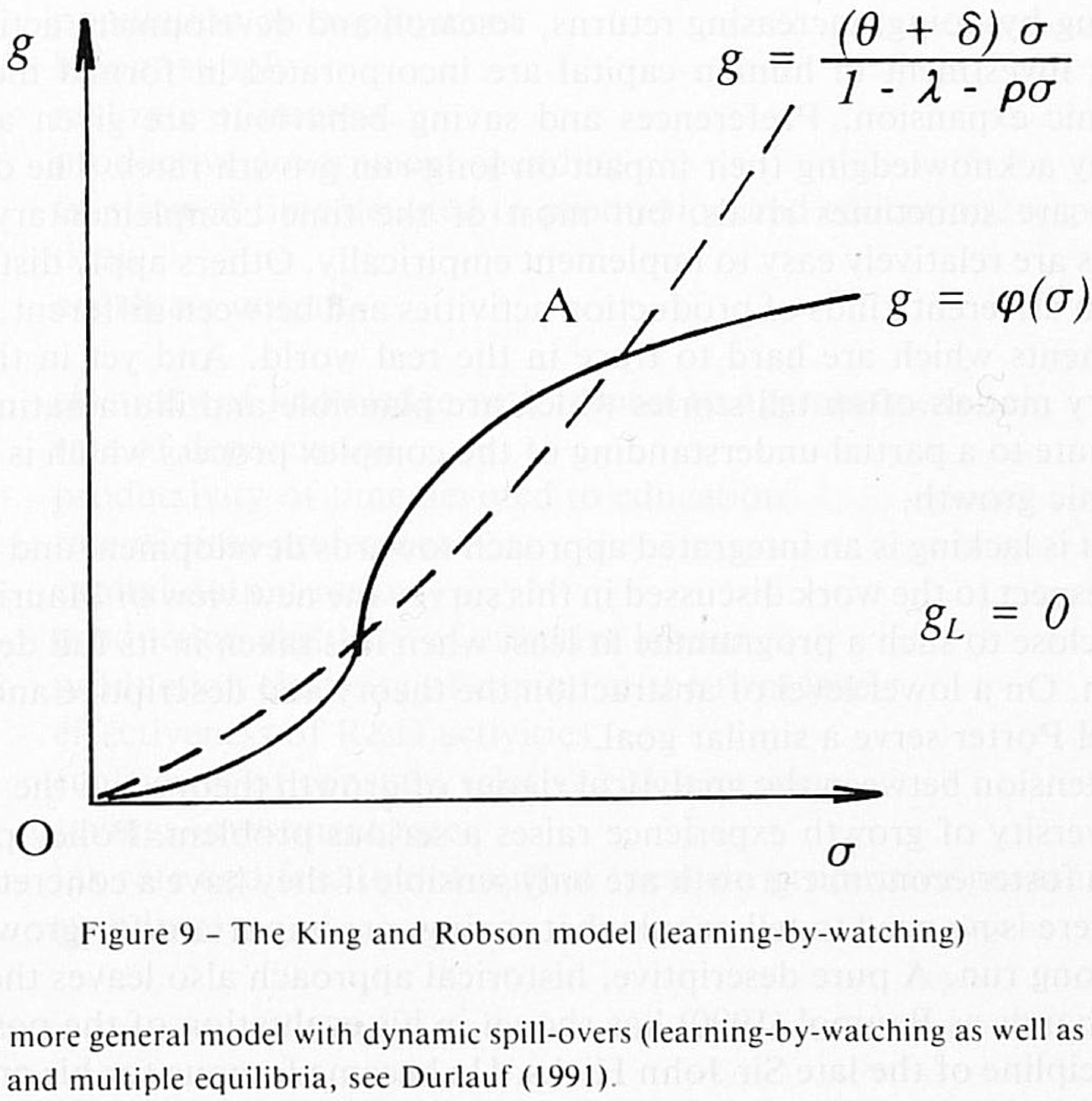

Figure 9 – The King and Robson model (learning-by-watching)

21 For a more general model with dynamic spill-overs (learning-by-watching as well as learning-by-doing) and multiple equilibria, see Durlauf (1991).

Figure 9. Depending on the parameter values there may be multiple equilibria. The steady-state solutions at point O (zero growth) and at point A (high growth) are stable. In contrast with the Stiglitz model the high growth rate solution is associated with a relatively *low* level of the capital-effective labour ratio (k). The zero growth equilibrium is attained for relatively *high* levels of k. Mature economies run the risk of overaccumulation and stagnation. Diminishing returns with respect to the reproducible factor dominate in this case, causing the interest rate to fall and driving the savings ratio down to zero.

The models discussed in this section are interesting attempts to model the intriguing view of growth stages, which may follow each other in time in an irregular way as economies experience major shocks and disturbances. However, the stories behind the models may reveal only part of the truth. An alternative view on the related problem of industrialisation is given in Murphy, Shleifer and Vishny (1989a,b). Analytical work on the decline of rich nations is in short supply. Empirical evidence nevertheless points in the direction of a real problem, which should be tackled by the theory of economic growth.

7 CONCLUSIONS

Where does the reconstruction of the theory of economic growth leave us? From a theoretical point of view there certainly has been some progress. Learning-by-doing, increasing returns, research and development activities as well as investment in human capital are incorporated in formal models of economic expansion. Preferences and saving behaviour are given a proper place by acknowledging their impact on long-run growth rates. The different models are sometimes rivals, but most of the time complementary. Some theories are relatively easy to implement empirically. Others apply distinctions between different kinds of production activities and between different kinds of investments which are hard to trace in the real world. And yet in the latter category models often tell stories which are plausible and illuminating. They contribute to a partial understanding of the complex process which is labelled economic growth.

What is lacking is an integrated approach towards development and growth. With respect to the work discussed in this survey the new view of Maurice Scott comes close to such a programme at least when it is taken in its full depth and breadth. On a lower level of abstraction the theory and descriptive analysis of Michael Porter serve a similar goal.

The tension between the analytical rigour of growth theory and the richness and diversity of growth experience raises a serious problem. Policy prescriptions to foster economic growth are only sensible if they have a concrete meaning. There is no need to tell people that savings are important for growth, also in the long run. A pure descriptive, historical approach also leaves them with empty hands as Baumol (1990) has shown in his evaluation of the position in our discipline of the late Sir John Hicks. He became famous for his analytical work, but would have preferred to have been awarded the Nobel prize for his work on economic history, which did not elicit much attention from economists. Endogenous growth theory in its many guises seems indispensable for disciplining our view on historical movements and positions held by countries in different stages of development. Recent theoretical contributions may be useful building blocks for a synthetic view on the process of economic growth. Much remains to be done as observed by Stern (1991) in his succinct evaluation of the theory and the challenge is still fascinating.

LIST OF SYMBOLS

C	aggregate consumption
g	growth rate of output
g_x	growth rate of variable x
h	labour productivity or human capital per worker
H	stock of skilled labour
H_R, H_Y	skilled labour allocated in the research sector and the production sector, respectively
K, $\bar{K}$	stock of physical capital and stock of broadly defined capital, respectively
k	capital-effective labour ratio
L	population or employment
N	labour supply
r	real rate of interest
S	productive government spending
u, $1-u$	fraction of time devoted to production and education, respectively
Y	aggregate output
γ	elasticity of knowledge with respect to aggregate capital
δ	rate of depreciation
ε	productivity of time devoted to education
θ	rate of time preference
κ	capital-output ratio
λ	production elasticity of effective labour
$1-\lambda$	production elasticity of capital at the firm level
ξ	effectiveness of R&D activities
ϱ	coefficient of constant relative risk aversion
σ	savings-investment rate
τ	tax rate and fraction of output spent on productive government spending

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Summary

RECONSTRUCTING GROWTH THEORY: A SURVEY

Recent developments in the theory of economic growth aim at endogenising long-run growth. The paper discusses models in which technological change arises as a by-product of certain economic activities as well as models where some economic actions are explicity aimed at technological improvements. In addition, separate sections are devoted to the specific reconstruction of growth theory by M. Scott and models explaining stages of economic development. For expositional purposes the algebra is kept to a minimum. The focus is on theoretical models for a closed economy. Empirical work is only mentioned in passing.